NREL/PO-510-31790
March 2002

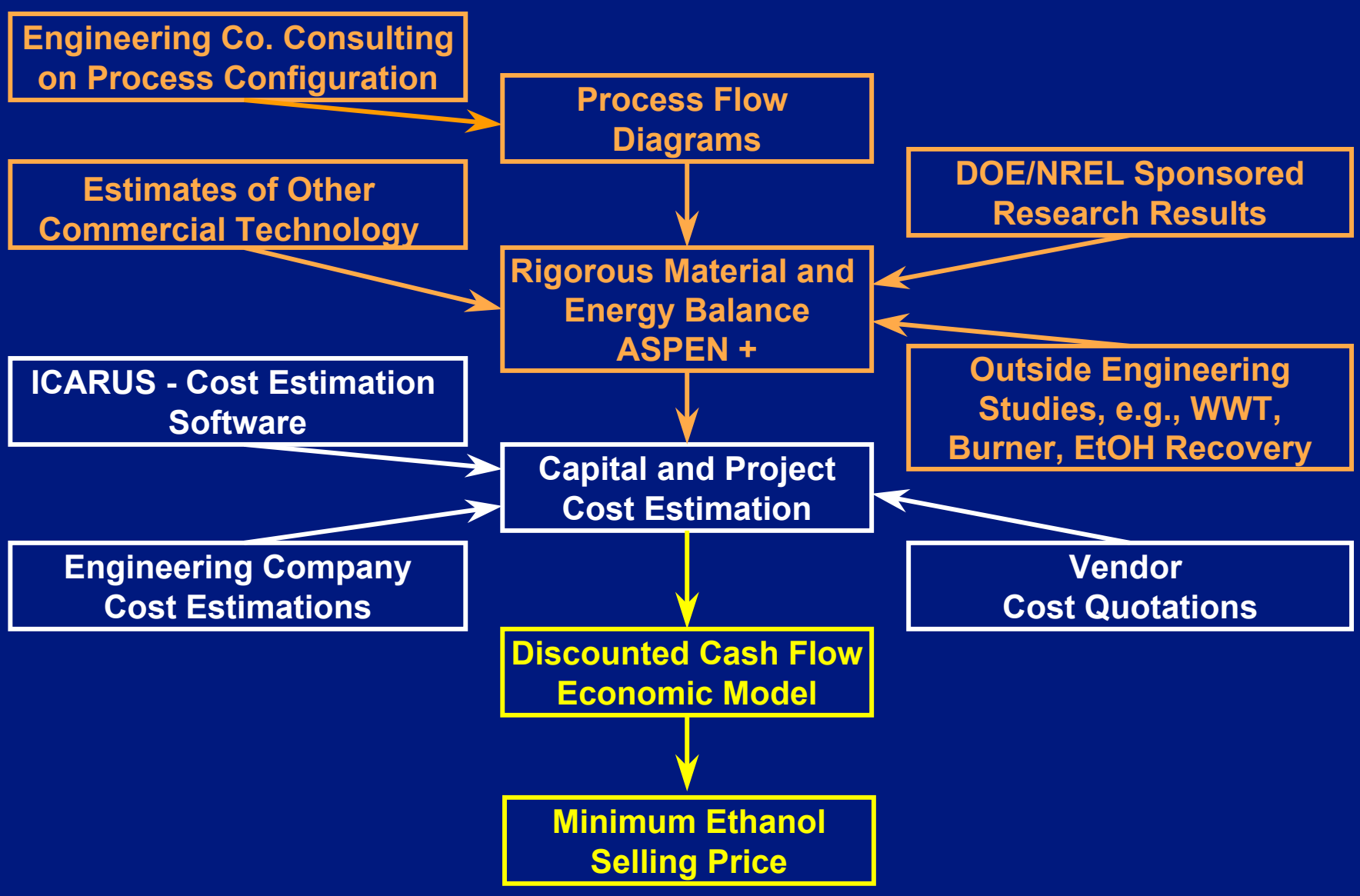
Technical and Economic Feasibility Assessment

- The primary objective is to understand technical feasibility and economics of biomass-to-ethanol processes
  - Helps determine research areas with “greatest bang for the buck”
  - Assists DOE and industry in determining the feasibility of bioethanol

Background

- NREL has been modeling biomass-to-ethanol processes for 15 years
  - Most recent full design report published in 1999 (*http://www.afdc.doe.gov/pdfs/3957.pdf*)
  - Updated report to be published in April 2002
- Minimum Ethanol Selling Price ($ per gallon ethanol) is the final result
  - Relative values between research options used to assist in guiding research
  - Absolute values used for policy analyses
- Scientific and technical insight is developed at many levels when conducting integrated process evaluations

Design and Assessment Methodology



For more information, see Wooley, et. al *"Process Design and Costing of Bioethanol Technology…"* Biotechnology Progress, 1999

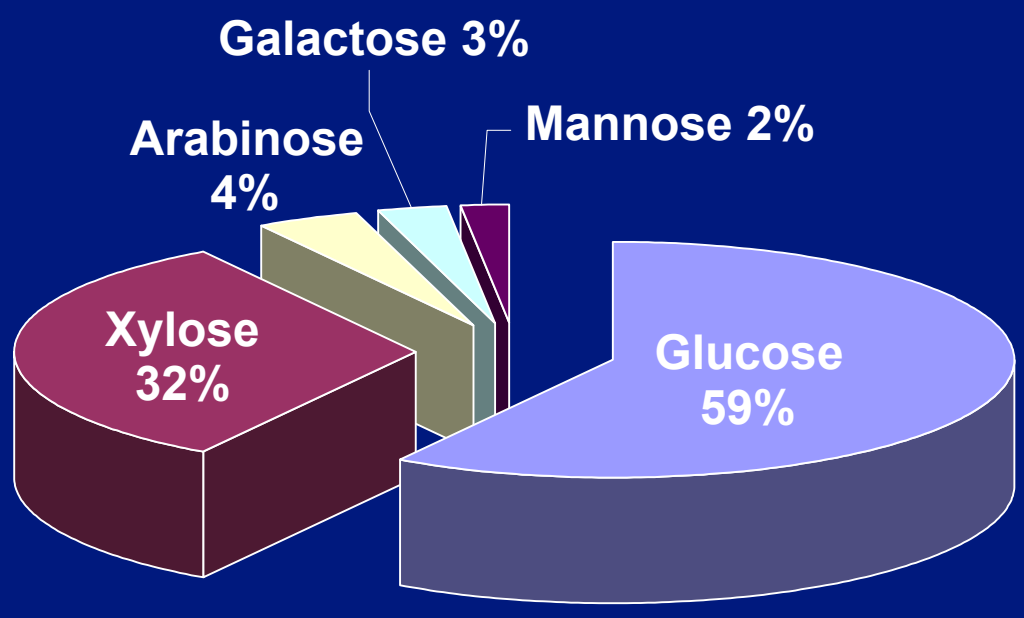
Supports DOE Sponsored Research

- Collect experimental results and full material balances around ***critical*** process areas
- Convert results to conceptual process designs and develop the "state of the technology" process model
- Use research hypotheses to improve process concepts and develop "target" process models
- Develop research projects to reach targets and attain economically viable process

Corn Stover Feedstock

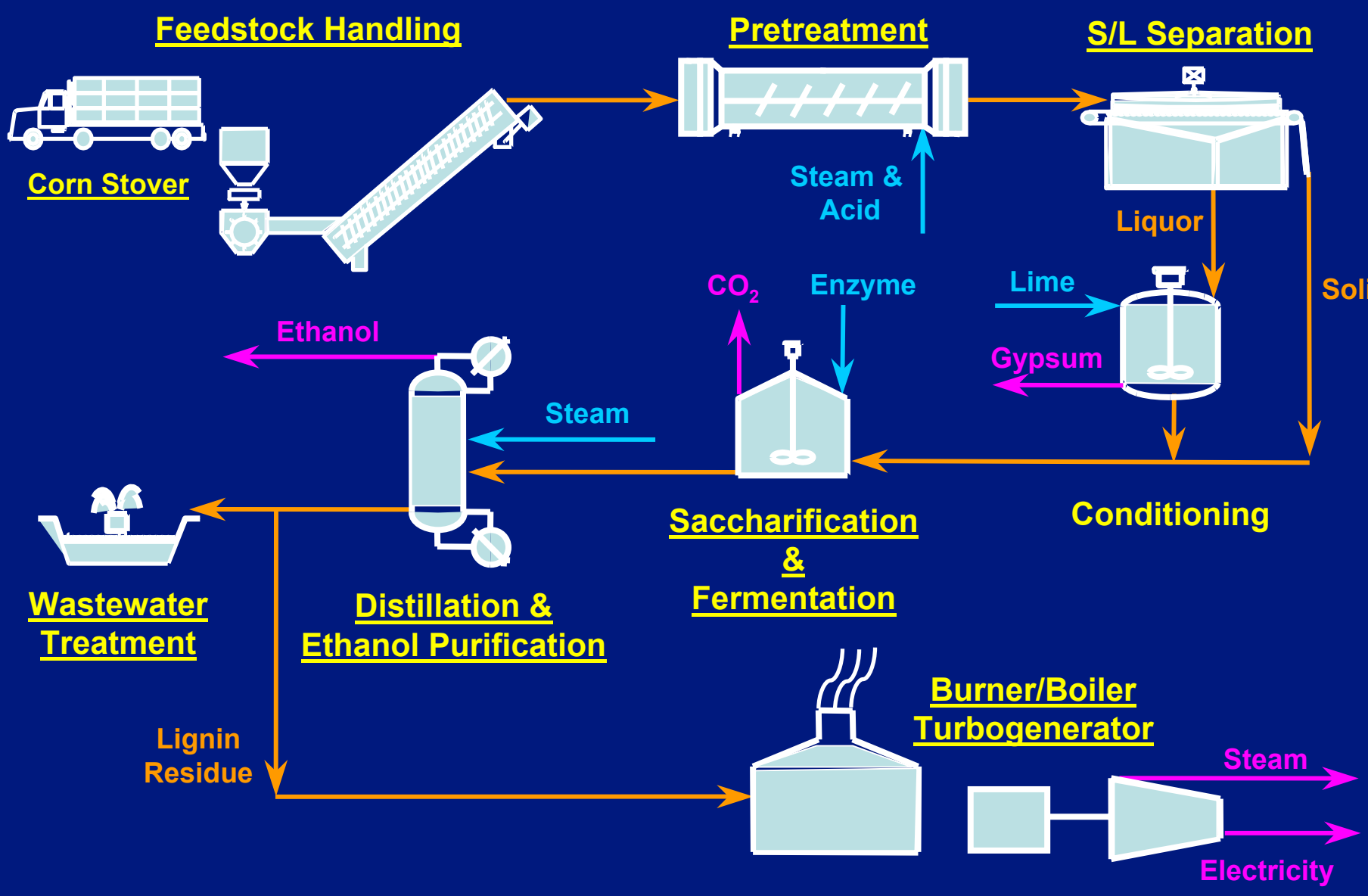
Model Parameter*	Value
Feedstock Cost	$35/dry ton
Cellulose Fraction	37.1%
Xylan Fraction	19.9%
Arabinan Fraction	2.5%
Mannan Fraction	1.3%
Galactan Fraction	1.7%
Lignin Fraction	18.2%

*** Composition based on NREL data**



Relative Fractions of Sugars Within Corn Stover

Conceptual Process Design for Corn Stover



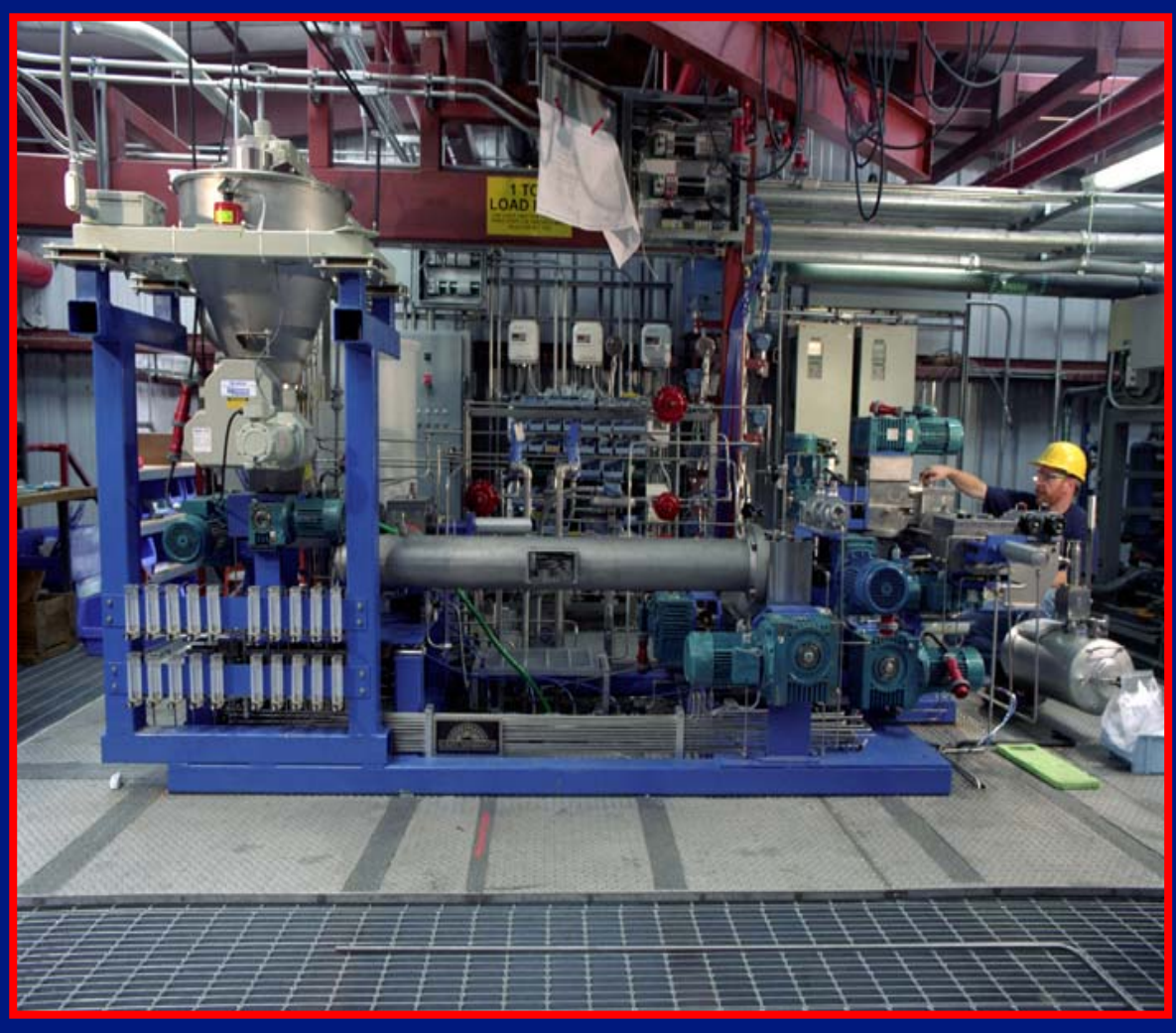
For more information, see Wooley, et. al *"Lignocellulosic Biomass to Ethanol Process Design and Economics…"* NREL/TP-580-2615 July, 1999

Feedstock Handling

- Brings biomass into facility
- Prepares biomass for pretreatment
- Need to develop improved handling systems

Pretreatment

- Converts hemicellulose to fermentable sugars
- Makes cellulose susceptible to enzymatic hydrolysis



Pretreatment

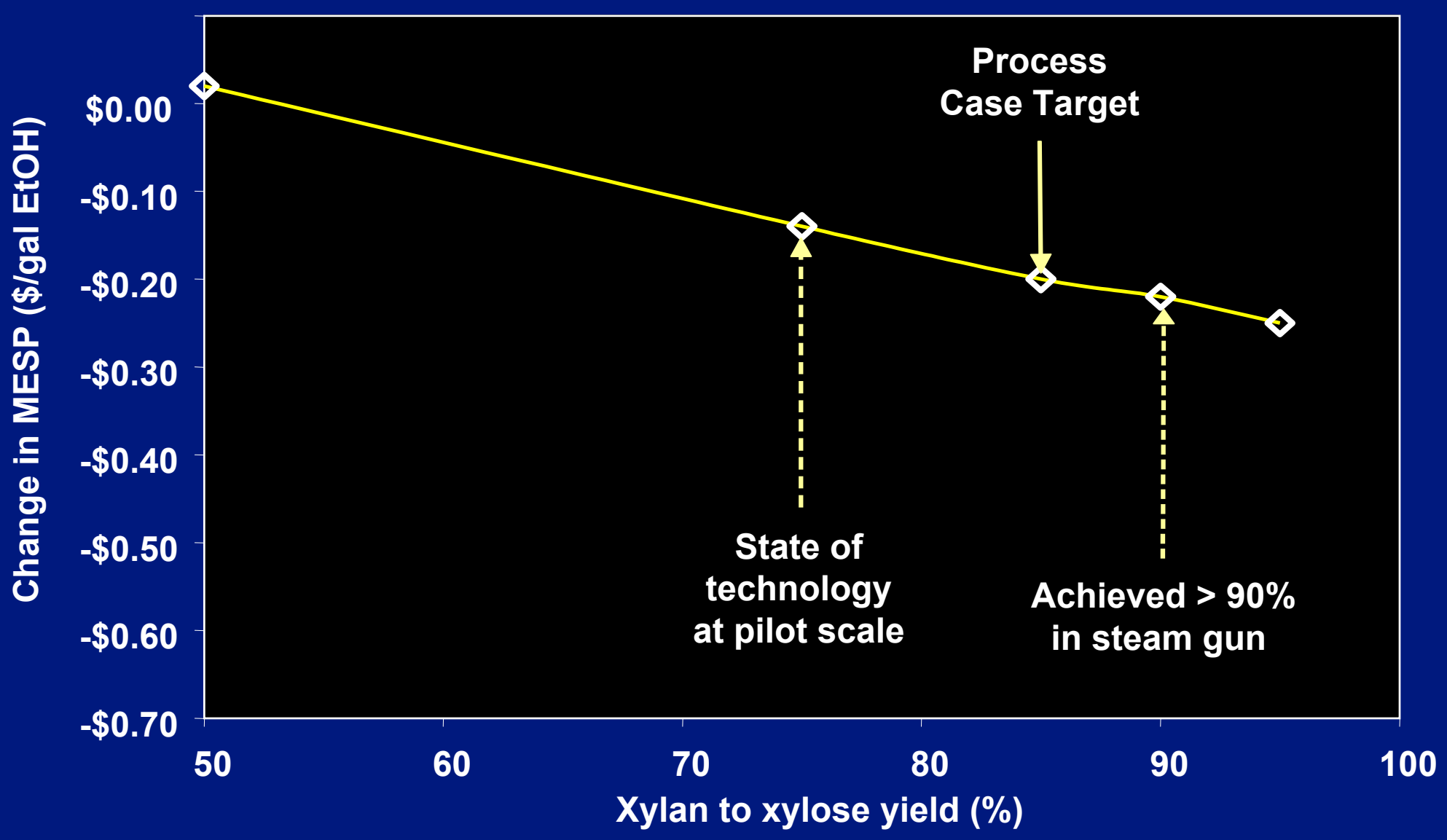
Conditions	Process Target
Technology	Dilute Acid
Reactor Solids Concentration	30 %
Residence Time	2 min
Acid Concentration	1.1 %
Temperature	190 °C
Reactor Metallurgy	Incoloy 825-clad

Parameter Source

- Corn stover Sunds hydrolyzer experiments
- Corn stover steam gun experiments
- Prior research on hardwood feedstocks

Pretreatment

$0.06/gal change for each 10% change in xylose yield



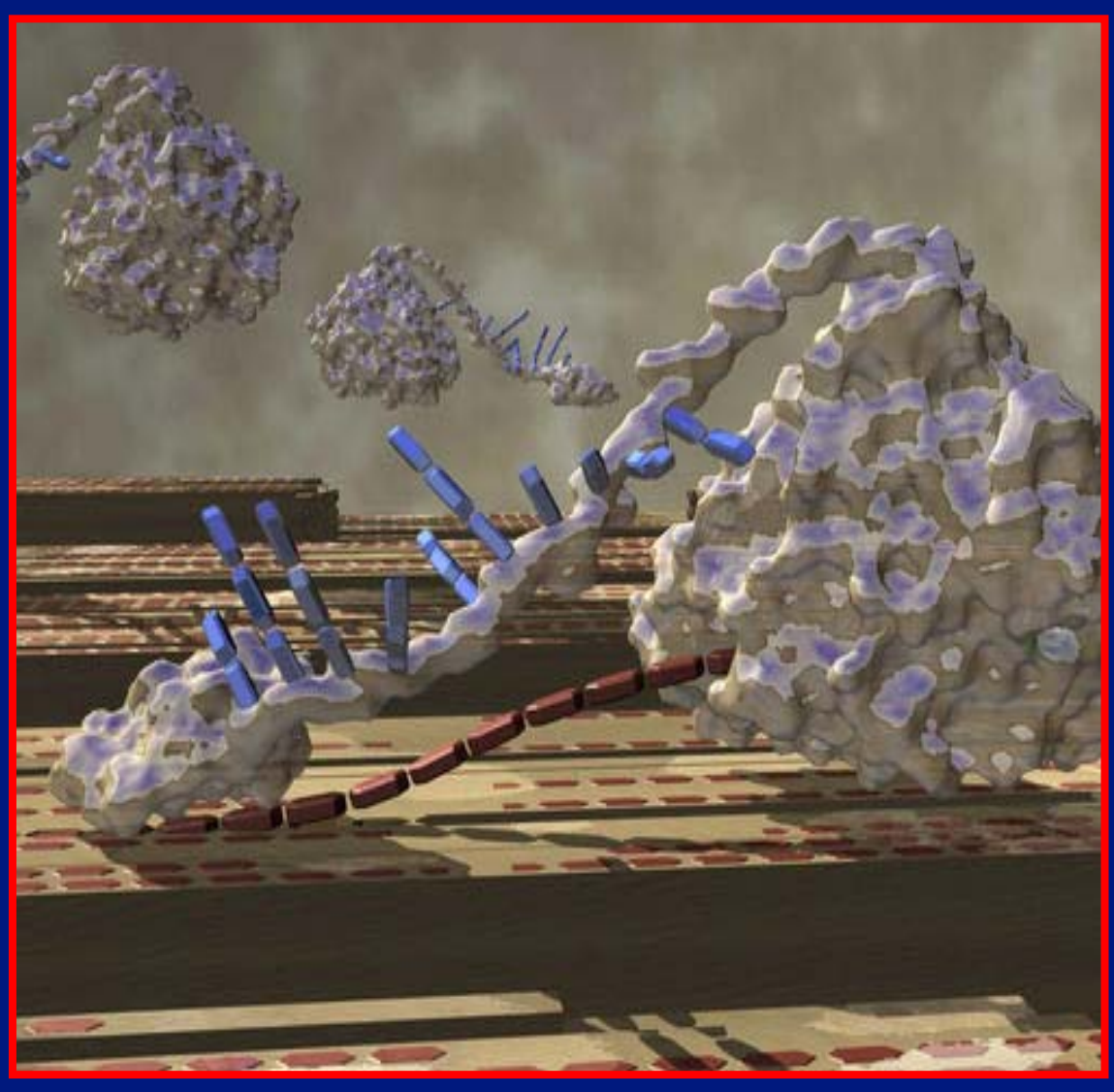
Solid/Liquid Separation and Conditioning

- Separation of pretreatment solids from liquor
- Conditioning of liquor fraction prior to fermentation

Conditions	Process Target
Equipment	Pressure Filter
Separation Temp	135 °C
Separation Pressure	5 atm
Conditioning	Overlime only
Wash / Hydrolyzate Ratio	0.58 kg/kg

Saccharification and Fermentation

Enzymatic hydrolysis of cellulose to glucose



Saccharification and Fermentation

Saccharification	Process Target
Enzyme Source	purchased
Enzyme Cost	$0.11/gal EtOH
SHF vs. SSF	Hybrid
Temperature	65 °C
Residence Time	1.5 days
Cellulose to Glucose Yield	90%

Parameter Source

- Enzyme cost is 10x-reduction from estimated cost for cellulase enzyme for existing markets
- Enzyme subcontracts w/ Genencor and Novozymes
- Hybrid design advantageous for more thermostable enzyme system

Saccharification and *Fermentation*

Microbial conversion of sugars to ethanol

Saccharification and *Fermentation*

Fermentation	Process Target
Residence Time	2 days
Temperature	37 °C
Nutrient Requirement	0.25% CSL(1) 0.33 g/L DAP(2)
Effective Solids Conc.	20%
Glucose to Ethanol Yield	92%
Xylose to Ethanol Yield	85%
Arabinose to Ethanol Yield	85%
Contamination Loss	5%

(1) Corn Steep Liquor
(2) Di-ammonium Phosphate

Parameter Source

- Based on prior conversion of hardwood hydrolyzates using *Z. mobilis*
  - Nutrients
- Strain improvements
  - Arabinose Yeast CRADA with CRA and NCGA
  - Other government sponsored research

Distillation and Ethanol Purification

- Separation of ethanol and CO_2 from "beer"
- Ethanol concentration in beer is about 5% w/w
- Primary Unit Operations
  - Distillation
  - Pressure-swing adsorption (molecular sieve)
  - Solid/liquid separation
  - Evaporation
- Operations well-known
- Process uncertainties
  - Solids behavior

Wastewater Treatment

- Anaerobic and aerobic treatment
- Reduce Biochemical Oxygen Demand (BOD)
- Recycle water

Burner/Boiler/Turbogenerator

- Boiler generates steam from lignin residue and evaporator syrup
- Excess electricity sold to power grid ($0.04/kWh credit)
- High capital cost area (35% of total installed cost)

Relative Cost Contribution by Area